REMR Technical Note CO-RR-1.4

PERFORMANCE OF BERMED REVETMENTS

PURPOSE: To report findings of a wave tank study to determine the effectiveness of a rubble berm for improving the performance of a riprap revetment.

APPLICATION: The technology in this note provides a method for quantifying the influence of a rubble berm on irregular wave runup on a riprap revetment. A berm can be included in the initial design of a coastal structure or added to an existing structure to improve its performance.

INTRODUCTION: The objective of a study conducted at the US Army Engineer Waterways Experiment Station Coastal Engineering Research Center (CERC) was to quantify the reduction in wave runup which could be attributed to the presence of a berm. In the study, reductions in wave runup were modest (up to about 20 percent), but the improvements in stability of the revetment and reductions in potential wave overtopping rates were quite substantial. Even when greatly deformed by severe wave conditions, the berm provided a high level of protection to the revetment (Ref. a).

TESTING: All tests were conducted in a 0.91-m-wide by 45.5-m-long by 0.91-m-deep wave flume. The piston-type wave generator was powered by an electro-hydraulic pump controlled by a computer-generated signal. The test section (Fig 1) modeled a 1:2 revetment on an impervious substratum protected by a filter layer and a layer of riprap. All tests were conducted with a JONSWAP spectrum. Runup was measured during a 256-sec interval, usually two times during a test (Ref. a).

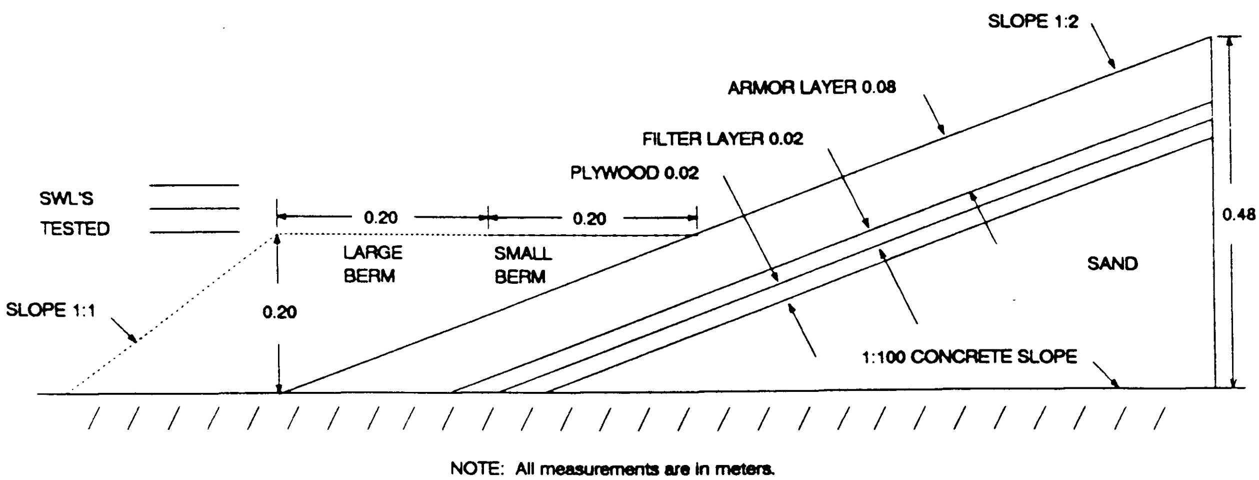

Figure 1. Test structure cross-section including both berms tested.

DATA ANALYSES:

a. Runup Analysis: A major effort in the analysis of the data was to develop a regression equation which would predict wave runup on either a standard, plane riprap revetment or on a riprap revetment fronted by a rubble berm. Such an equation could be used to make objective estimates of the effects of the berm on wave runup. After considerable trial and error experimentation with various functional forms and numerous variables and pairings of variables, the following equation appeared to be the most satisfactory:

$$R_{max}/H_{mo} = \exp[c0 + c1 * (H_{mo}/L_o) + c2*B'] \quad (1)$$

where R_{max} is the elevation of the maximum observed wave runup; H_{mo} is the incident zeroth-moment wave height at the toe of the structure; c0, c1, and c2 are dimensionless regression coefficients with values of 0.695, -11.269, and -0.158, respectively; L_o is the deep-water wave length associated with the period of peak energy density of the incident spectrum; and B′ is a dimensionless berm-size parameter given by

$$B' = [W_B/\mathrm{sqrt}(H_{mo} * L_o)] * (h_B/d_s) \quad (2)$$

where W_B is the width of the berm, h_B is the height of the berm above the toe, and d_s is the water depth at the toe of the structure. The formulation of the berm influence given by Equations 1 and 2 is surprisingly similar to the analysis of monochromatic wave runup data by Battjes (Ref. b). The results are consistent with findings by Battjes in that it is necessary to use both the width and height of a berm and the height and period of the waves to properly account for the reduction in runup. Also improved fit can be obtained by including the berm height within the berm-size parameter. Equation 1 explains about 64 percent of the variance in the data, which is not a particularly good fit for laboratory data. The relatively poor fit appears to be the result of the inherently complex interaction of irregular waves with a berm on a rough and porous structure. Also, visual observations of the elevation of maximum runup produce a runup variable which is less statistically stable than desirable and is somewhat subjective.

In spite of the limitations of the data, the three coefficients are highly significant, and the form of Equation 1 is logical, based on current understanding of irregular wave runup on riprap. The third term (r = exp(c2 * B′)) in Equation 1 can be regarded as a runup reduction factor, r, due to the influence of the berm. The first two terms of Equation 2 give the relative runup on a riprap revetment with a 1 on 2 slope without a berm. A limiting value for relative runup for waves of low steepness of exp(c0) = 2.0 seems low but is consistent with visual observations.

b. Stability Analysis: Two dependent variables were used in the stability analysis: S_2 damage and the maximum penetration of damage into the armor layer, e_{max}. S_2 is defined as

$$S_2 = A_d/d_{50}^2 \tag{3}$$

where A_d is the volume of damage per unit length of structure and d_{50} is the median armor stone diameter. For this series of tests, S_2 damage was measured above the elevation of the berm. Since the berm was considered sacrificial, the adjustment of the berm to wave attack was not regarded as damage. e_{max} was calculated by finding the maximum difference between the armor layer survey before waves were run and the survey at the end of the test after all wave generation was completed. e_{max} was measured normal to the surface of the armor and was normalized by the armor layer thickness; that is

$$e'_{max} = e_{max}/r_a \tag{4}$$

where e'_{max} is the normalized maximum penetration of damage and r_a is the armor layer thickness.

S_2 damage can be estimated using the following equation:

$$S_2 = 1.0 * (N_s\hat{}3.57) * \exp(-4.38 * B') \tag{5}$$

and e'_{max} can be estimated using:

$$e'_{max} = 0.0775 * (N_s\hat{}2.75) * \exp(-3.22 * B') \tag{6}$$

where the stability number N_s is defined as

$$N_s = H_{mo}/\{(W_{50}/W_r)\hat{}(1/3) * [W_r/W_w)-1]\} \tag{7}$$

where W_{50} is the median stone weight and W_r and W_w are the unit weights of the armor stone and water respectively. Typically, a value of $S_2 = 2$ is regarded as about the zero-damage level for revetments (Ref. c).

A Quasi-Newton non-linear error minimization method was used to determine the coefficients in Equations 6 and 7 rather than logarithms and standard regression analysis. The non-linear minimization method seemed to produce equations which showed a better balance of differences between predicted and observed or residuals.

Linear correlation between predicted and observed values of S_2 and e'_{max} are 0.813 and 0.878, respectively, indicating that Equations 4 and 5 are better predictors than Equation 1. However, when Equation 1 is solved for R_{max} rather than R_{max}/H_{mo}, the correlation between predicted and observed is 0.97. This figure indicates that R_{max} can be predicted better than the dimensionless measures of damage, a finding that was not surprising because of problems in making accurate estimates of damage in other rubble mound stability studies (Ref. c, d, & e).

c. <u>Runup and Damage:</u> A porous rubble berm is a good dissipator of wave energy. It disrupts the wave action near the structure so that the intensity of the wave uprush is considerably diminished. The reductions in runup elevations observed in this study were relatively modest, up to about 15 to 20 percent, but the reductions in damage were quite large. The identical form of the reduction factor component of Equations 1 and 6 provides an easy way to compare the reduction in runup to the reduction in damage. As an example, consider a berm which reduces the runup 10 percent; therefore

$$r(\text{runup}) = \exp(-0.158 * B') = 0.90$$

$$r(S_2) = \exp(-4.38 * B')$$

Solving for the S_2 reduction factor gives $r(S_2) = 0.054$, or an expected reduction in damage by a factor of over 18.

d. Estimating Reduction in Overtopping Rates: Generally, riprap revetments are not designed to be overtopped; however, during high water and severe wave conditions, the probability of overtopping may be significant. The addition of a rubble berm provides a logical way to reduce overtopping rates to acceptable levels as demonstrated in the following example problem. (The potential runup approach to computing overtopping rates given in the Shore Protection Manual (SPM) (Ref. f) is used.) Assume a runup reduction factor for a bermed revetment of 10 percent or r(runup) = 0.9, a potential exceedance of 3.5 percent, and the potential runup R_{max} exceeds the freeboard of a non-bermed revetment by 15 percent. The ratio of overtopping rates for a revetment with no berm to that with a berm is

$$Q(\text{no berm})/Q(\text{berm}) = [(0.15/2.15)/(0.035/2.035)]\hat{}(0.1085/a)$$

$$= (4.06)\hat{}(0.1085/a)$$

where Q is the overtopping rate per unit length of structure per unit time, and a is an overtopping coefficient which varies from 0.045 to 0.090 for the riprap revetment with a 1 on 1.5 slope shown in the SPM. Continuing the example problem using the upper and lower limits of a gives

For $a = 0.045$: $Q(\text{no berm})/Q(\text{berm}) = 29.3$

For $a = 0.090$: $Q(\text{no berm})/Q(\text{berm}) = 5.4$

Clearly, modest reductions in runup can translate into impressive reductions in overtopping. The values given in the example are overtopping rates associated with the maximum runup (overtopping quantities for a wave can be obtained by multiplying the rate by the wave period). Reductions in average overtopping rates for irregular wave action would be greater since the berm would reduce not only the rate for R_{max} but also the number of waves overtopping.

e. Comparisons with Earlier Studies: When the runups on plane 1 on 2 riprap revetments from this study (Ref. a) are compared to those of Ahrens and Heimbaugh (Ref. g), systematic differences are observed. This study consistently has lower values of relative runup than observed by Ahrens and Heimbaugh. Differences appear to be associated with observations typically differing by two to four centimeters. This type of discrepancy suggests that visual runup observations are quite observer sensitive since different observers were used on the different studies. Since observations conducted during the study by Ahrens and Heimbaugh were made by a single and thoroughly experienced observer, they are considered superior to those of this study. However, observations from this study are sufficiently consistent to provide a useful berm runup reduction factor (Equation 3) which can be incorporated into the runup equation of Ahrens and Heimbaugh as follows:

$$R_{max}/H_{mo} = (r*\xi)/(1.0 + b*\xi) \qquad (8)$$

where ξ is the surf similarity parameter given by

$$\xi = \tan\theta/\mathrm{sqrt}(H_{mo}/L_o) \qquad (9)$$

where tan θ is the tangent of the angle θ between the revetment slope and the horizontal, and b is a dimensionless runup coefficient with a value of 0.247. Further justification for estimating maximum runup elevations with Equation 8 are given in Ward and Ahrens (Ref. a).

<u>CONCLUSIONS:</u> The study reported in this technical note supports earlier findings that even modest reductions in runup, about 10 percent, can be associated with substantial improvements in the stability of a revetment and reductions in potential wave overtopping rates.

A problem was identified that relates to visual observation of maximum runup elevations made by different observers. Because of this problem, a renewed effort is being made at CERC to develop a digital wave runup gage which can be used on rough and porous slopes and for irregular wave conditions.

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